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ARTICLE TITLE	DIAGNOSTIC, MEASUREMENT, AND MONITORING PERFORMANCE OF INTRAORAL SCANNER-BASED WORKFLOWS FOR EROSION TOOTH WEAR: A NARRATIVE REVIEW OF CLINICAL AND EXPERIMENTAL EVIDENCE
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DIAGNOSTIC, MEASUREMENT, AND MONITORING PERFORMANCE OF INTRAORAL SCANNER-BASED WORKFLOWS FOR EROSIVE TOOTH WEAR: A NARRATIVE REVIEW OF CLINICAL AND EXPERIMENTAL EVIDENCE

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ABSTRACT

Background: Erosive tooth wear (ETW) requires reliable documentation of severity and progression. Intraoral scanner (IOS)-based workflows can generate serial three-dimensional datasets, but their diagnostic and measurement performance depends on acquisition, registration, and analysis procedures.

Objective: To review the diagnostic, measurement, and monitoring performance of IOS-based workflows for ETW.

Methods: PubMed/MEDLINE, Embase, and Scopus were searched on 1 September 2026 without date or language restrictions, supplemented by reference-list and citation searching. Clinical diagnostic, agreement, longitudinal, method-comparison, and experimental validation studies were considered. Methodological quality was appraised narratively and matched to study design, and findings were synthesised by evidence domain because designs, reference standards, units of analysis, scanners, software, and outcomes were heterogeneous.

Results: Twenty clinical and experimental reports published between 2016 and 2026 were discussed. Direct clinical evidence was limited. One 2026 study reported high sensitivity but lower specificity for scan-based assessment relative to clinical BEWE. Experimental studies generally detected progressive surface loss, but performance varied by scanner, software, registration method, lesion severity, and outcome metric. Longitudinal studies supported quantitative documentation, although alignment failures, clustered observations, and overlapping cohorts limited inference.

Conclusions: Predominantly small and heterogeneous evidence suggests that IOS-based workflows may be useful adjuncts for ETW documentation and longitudinal monitoring. They should complement rather than replace clinical assessment. System-specific thresholds should not be generalised without standardised prospective clinical validation.

KEYWORDS

Erosive Tooth Wear, Intraoral Scanning, Digital Dentistry, Three-dimensional Imaging, Longitudinal Monitoring, Diagnostic Accuracy

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1. Introduction

Erosive tooth wear (ETW) is tooth wear in which dental erosion is the primary aetiological factor; chemical dissolution by non-bacterial acids may be accelerated by mechanical processes (Schlueter et al., 2020). Clinically, ETW can progress from loss of surface texture to substantial enamel and dentine loss, with consequences for sensitivity, function, aesthetics, and restorative complexity. Early lesions may be subtle, whereas advanced progression can compromise function and appearance and may require complex restorative management.

Reliable monitoring is clinically important because existing tissue loss does not by itself demonstrate ongoing activity. Management depends on distinguishing historical loss from active progression. The Basic Erosive Wear Examination (BEWE) is a pragmatic ordinal screening index, but visual scoring remains examiner-dependent and may not capture small longitudinal changes (Bartlett et al., 2008). BEWE 2.0 was introduced in 2026 to clarify the distinction between scores 0 and 1 and add a new level 4 score for severe loss (≥ 2 mm loss of crown height or 2 mm horizontal cervical wear); the included studies used the original BEWE framework, which should be considered when assessing comparability with future studies (Bartlett et al., 2026).

Digital dentistry offers a potentially complementary approach. Modern IOS systems capture three-dimensional representations of the dentition that can be stored and compared longitudinally. Sequential datasets may be registered and analysed to estimate linear profile loss, maximum point loss, surface deviations, area changes or volumetric loss. Digital models may also be magnified and viewed from unrestricted angles, potentially improving documentation of morphology that is difficult to inspect directly.

Nevertheless, an IOS measurement is not generated by scanner hardware alone. The final result reflects the entire digital pipeline: optical acquisition, mesh reconstruction, scan density, registration algorithm, choice of stable reference surfaces, segmentation, analysis software and selected metric. Registration is especially important in longitudinal ETW because the surfaces used as references may themselves be affected by progressive wear. Controlled laboratory studies can create stable reference regions, whereas clinical workflows must deal with saliva, patient movement, limited posterior access, restorations, fractures and biological changes over time.

The literature has expanded from proof-of-concept studies of digital wear measurement to laboratory validation against profilometry, confocal microscopy and micro-computed tomography, as well as clinical agreement and longitudinal monitoring studies (Meireles et al., 2016; Alharbi et al., 2026). These studies address related but distinct questions. Analytical sensitivity under controlled conditions is not equivalent to diagnostic accuracy *in vivo*; agreement with a clinical index is not the same as trueness against a physical reference standard; and correlation between two methods does not demonstrate interchangeability.

Previous reviews have generally addressed digital tooth-wear assessment across mixed aetiologies or technologies (Angelone et al., 2023; O'Toole et al., 2023). This review focuses specifically on ETW and distinguishes four constructs that should not be conflated: presence or severity of ETW, agreement with an ordinal clinical index, active longitudinal progression, and quantitative physical surface loss. It asks how accurately and reproducibly IOS-based acquisition-and-analysis workflows detect, classify, quantify, or monitor ETW in patients, on dental casts, in human teeth, and in experimental specimens whose use is scientifically justified, compared with clinical assessment or an independent reference method.

Accordingly, this narrative review critically evaluates the diagnostic, measurement, and monitoring performance of IOS-based workflows for ETW. Secondary objectives are to identify methodological determinants of performance, assess the directness and certainty of the evidence, and define priorities for standardised clinical validation.

2. Methods

2.1 Review design

This narrative review synthesises clinical and experimental evidence on IOS-based workflows for ETW. The review question, the four evidence constructs, and the synthesis domains were defined before the evidence was assembled, and the search strategy is reported in full to support transparency and reproducibility. Formal systematic-review procedures, including prospective protocol registration, duplicate independent study selection, and itemised risk-of-bias instruments, were not applied; the implications of this design are addressed in the limitations.

Because the evidence base included clinical diagnostic, agreement, longitudinal, method-comparison, and experimental validation studies, methodological appraisal was matched to study design, and observations were not converted into a common numerical scale across designs.

2.2 Scope of the evidence

Population/material: patients, human teeth, dental casts, and bovine specimens, used where scientifically justified, exposed to an erosive or erosive-abrasive model. Index workflow: direct IOS acquisition, IOS digitisation of casts, or IOS scanning of experimental specimens followed by visual or software-based analysis. Target condition: ETW presence or severity, active ETW progression, or experimentally induced erosive/erosive-abrasive tissue loss. Reference/comparator: clinical BEWE, conventional casts or photographs, profilometry, confocal microscopy, micro-CT, controlled exposure time, or another prespecified measurement workflow. Outcomes: diagnostic accuracy, agreement, reliability, trueness, precision, measurement error, limits of agreement, and longitudinal change. Considered designs: diagnostic-accuracy, agreement/reliability, longitudinal cohort, method-comparison, and experimental validation studies.

Laboratory scanners, profilometry, optical coherence tomography, photography, confocal microscopy, and micro-computed tomography were considered only as comparators or reference methods. Studies were classified according to whether they evaluated scanner acquisition, analysis software, registration strategy, or the complete workflow.

Reports on general or non-carious tooth wear were considered only where ETW was explicitly defined, an erosive or erosive-abrasive model was used, or ETW-specific results or measurement-performance findings were separable and transferable to ETW workflows. Reports in which IOS served only as an outcome-measurement instrument for an intervention were not considered unless scanner or workflow performance was a stated objective.

2.3 Information sources and search strategy

PubMed/MEDLINE, Embase, and Scopus were searched on 1 September 2026. Search strategies combined controlled vocabulary, where available, with free-text terms for tooth erosion/erosive tooth wear and intraoral scanning/three-dimensional digital modelling. No date or language restrictions were applied. Records in languages other than English were assessed with machine-assisted translation where necessary. Full database-specific strategies, platforms, and record counts are reported in Supplementary Table S1.

The database searches retrieved 352 records from PubMed/MEDLINE, 146 from Embase, and 211 from Scopus (709 records before deduplication). Reference lists and targeted citation searching were used as supplementary methods. The search strategy was not peer reviewed using a standard checklist, and grey-literature searching was limited; these constraints are acknowledged as sources of potential retrieval bias.

2.4 Study identification and selection

Database exports were combined and deduplicated using DOI matching and normalised title comparison, followed by manual reconciliation of uncertain matches. Different reports from the same underlying study were retained as separate reports and linked as study families rather than treated as bibliographic duplicates.

Titles and abstracts were screened for relevance, followed by full-text assessment of potentially relevant records. Selection was performed by one reviewer, which is acknowledged as a limitation of this narrative synthesis.

2.5 Data collection

Data were collected using a structured form covering publication year, country and setting, design, population/material, sample size at each hierarchical level, acquisition pathway, scanner and software versions, scan and registration methods, stable reference surfaces, comparator, exposure or follow-up, outcome definition, effect estimate and precision, missing or excluded scans, handling of clustering, funding, manufacturer involvement, conflicts of interest, and study family. When several relevant outcomes or time points were reported, all clinically distinct outcomes were retained and prioritised by construct: diagnostic accuracy, agreement/reliability, longitudinal progression, and, finally, analytical measurement performance. Unclear or unreported data were recorded as such rather than inferred.

For every report, the unit of analysis was recorded as participant, tooth, surface, specimen, and/or repeated measurement. Analyses based on multiple teeth or surfaces per participant were flagged when within-participant dependence was not addressed. Reports were linked when authors, recruitment setting, sample sizes, and follow-up periods suggested overlapping datasets.

2.6 Methodological appraisal

Methodological quality was appraised narratively, matched to study design. Experimental in vitro and ex vivo studies were considered with respect to specimen numbers, randomisation, blinding, prespecified analysis, and reference-method quality; clinical studies were considered with respect to sample selection, examiner blinding and calibration, attrition, handling of repeated measures, and statistical analysis. Method-comparison studies were additionally considered with respect to acquisition order, washout, and reference-method quality. Observations were kept at the level of design-specific judgments and were not converted into a common numerical scale.

Appraisal was conducted by one reviewer and is presented as a structured narrative assessment rather than a formal risk-of-bias rating.

2.7 Data synthesis

Meta-analysis was not undertaken because the evidence differed substantially in setting, material, scanner generation, software, registration, comparator, lesion severity, follow-up, unit of analysis, and outcome definition. Studies were assigned to three prespecified domains: clinical diagnostic/agreement performance, longitudinal clinical monitoring, and experimental measurement validation. When a report contributed to more than one domain, results were presented by construct without double-counting the report. All relevant time points were retained; emphasis was placed on the earliest detectable change and the final exposure or follow-up. Narrower quantitative pooling was considered but rejected because no clinically coherent subgroup contained sufficiently comparable estimates.

2.8 Certainty of the evidence

Results were synthesised by separating diagnostic accuracy from agreement, correlation from interchangeability, and repeatability from trueness. Qualitative sensitivity considerations examined direct clinical IOS only, exclusion of cast-based or mixed acquisition pathways, exclusion of reports with high risk or insufficient information, and clinical versus experimental evidence. Certainty was appraised separately for clinical diagnostic/agreement performance, longitudinal clinical monitoring, and experimental measurement validation using an adapted narrative framework considering risk of bias, directness, consistency, precision, sample size, platform dependence, selective reporting, conflicts of interest, and clinical transferability.

Formal assessment of publication bias with funnel plots was not appropriate because each evidence domain contained few studies and designs and outcomes were substantially heterogeneous. Publication bias and selective outcome reporting were therefore considered qualitatively by examining outcome completeness, unexplained omissions, small-study patterns, and manufacturer involvement.

3. Findings

3.1 Evidence base

The database searches identified 709 records. Screening of titles, abstracts, and full texts identified 18 reports for detailed discussion, and two further reports, including Machado et al. (2022), were identified through reference-list and citation searching, yielding 20 reports published between 2016 and 2026.

The 20 discussed reports comprised clinical agreement studies, longitudinal cohorts, method-comparison studies, and in vitro/ex vivo validation experiments. Several reports arose from related cohorts; therefore, report counts should not be interpreted as 20 fully independent participant datasets. One additional method-comparison report (Machado et al., 2022) is appraised in Table 2 but is not tabulated in Table 1 because it did not contribute primary ETW diagnostic or measurement data. Study-family links and acquisition pathways are shown in Table 1.

3.2 Characteristics of the discussed reports

Characteristics of the discussed reports are summarised in Table 1. Evidence included direct clinical IOS acquisition, IOS digitisation of historical casts, mixed acquisition pathways, and controlled experimental models. Direct clinical diagnostic evidence remained a minority of the evidence base.

Table 1. Characteristics and principal findings of the discussed reports

Study / study family	Design and analysis unit	IOS-based workflow	Comparator / reference	Main result and interpretation
Meireles et al., 2016	In vitro; 8 extracted teeth/specimens	Digital intra-oral optical scanner; automated 3D computer-vision analysis	Experimentally produced wear/reference surface	Feasibility of automated digital wear estimation.
Alaraudanjoki et al., 2017	Clinical agreement; 586 adults	Direct 3D intraoral models; BEWE scoring	Clinical BEWE	High digital reproducibility; inter-method differences, especially severe/upper posterior wear.
Marro et al., 2018	Retrospective longitudinal; 120 adolescents; 1920 posterior sextants	Casts digitised with TRIOS; 3D BEWE	Conventional casts/BEWE	Strong method correlation (τ_b 0.74); 3D scoring identified more initial changes.

Study / study family	Design and analysis unit	IOS-based workflow	Comparator / reference	Main result and interpretation
Kumar et al., 2019	In vitro; 8 natural buccal enamel samples	3M True Definition; Geomagic Control	Progressive citric-acid exposure	Profile loss tracked exposure; volumetric estimates inconsistent at minimal wear.
Marro et al., 2020	Retrospective quantitative monitoring; 96 first-molar surface pairs	TRIOS digitised casts; WearCompare	Visual BEWE progression	Volume threshold - 1.22 mm ³ : sensitivity 79%, specificity 61%, AUC 0.80.
Michou et al., 2020	In vitro; 12 human teeth in artificial arches	TRIOS 3; Patient Monitoring	Erosive-abrasive challenge	0.08 mm significant loss after 3 h; $r_s = 0.971$; workflow-specific error threshold.
O'Toole et al., 2020, J Dent	Clinical longitudinal; 29 analysed patients; 556 surfaces	True Definition; WearCompare	Serial full-arch IOS	Multilevel modelling of 556 surfaces; exclusions and reliability reported at study level.
O'Toole et al., 2020, JMIR	Clinical method comparison; longitudinal wear data; 76 surfaces	True Definition and analysis software	Laser profilometry; Geomagic/WearCompare	Scanner, software and metric all materially influenced results.
Machado et al., 2022	In vitro; 15 unpolished bovine crowns; repeated measurements	TRIOS 3; WearCompare (volume/area) and Patient Monitoring (depth)	Citric-acid exposure time; no independent metrological reference	Loss increased with exposure; statistical detection occurred at 72 h (volume), 96 h (area), and 144 h (depth); high correlations do not establish agreement.
Witecy et al., 2021	In vitro; 16 human enamel specimens	TRIOS 3; CS3600; internal/external software	Non-contact profilometry	Detected stepwise loss; generally good Bland-Altman agreement.
Marro et al., 2022	Prospective longitudinal; 70 adolescents in quantitative analysis; 295 surfaces	TRIOS 3 serial IOS; quantitative volume loss	Baseline BEWE/risk factors	Multilevel analysis demonstrated measurable 1-year progression and associated predictors.
Jablonski-Momeni et al., 2023	In vitro; 58 human teeth	IOS 3D assessment	QLF; repeated erosive cycles	IOS detected progressive erosive changes and correlated with QLF.
Loumprinis et al., 2024	In vitro alignment study	TRIOS 4; Patient Monitoring / alternative alignments	Multiple registration strategies	No universally superior alignment; stable references remain important.

Study / study family	Design and analysis unit	IOS-based workflow	Comparator / reference	Main result and interpretation
Bors et al., 2025	10-year cohort; 517 follow-up; digital subset n=40	Digitised baseline casts + direct Medit i700 follow-up	BEWE	Digital loss correlated with BEWE; mixed acquisition pathway limits inference.
Valdivia Tapia et al., 2025	In vitro diagnostic agreement; extracted teeth	TRIOS 4 3D colour models	Direct visual BEWE	Weighted kappa about 0.70; weakest agreement for BEWE 1.
Aly et al., 2025	In vitro; 36 enamel specimens	Carestream 3700	3D confocal laser microscopy	IOS detected loss after 3 and 6 h; early 1-h change not consistently detected.
Tsiafitsa et al., 2026	In vitro; 10 premolars; repeated scans	TRIOS 3, Primescan, Omnicam	Micro-CT	Significant scanner differences; none interchangeable with micro-CT.
Valdivia-Tapia et al., 2026	In vitro primary teeth; ETW subset 164 molars	TRIOS 4 colour 3D models	Direct visual BEWE	Kappa 0.58; 80% agreement; strongest concordance at BEWE 2.
O'Toole et al., 2026	Clinical diagnostic study; 61 adults; 1600 teeth/4797 surfaces	TRIOS 5; on-scan and automated analysis	Clinical BEWE/dentine exposure	On-scan sensitivity 0.98, specificity 0.56; automated assessment had different trade-offs.
Alharbi et al., 2026	Retrospective digital agreement; 394 occlusal surfaces	iTero 3D scans	2D clinical photographs	BEWE weighted kappa 0.57; moderate agreement between digital modalities.

Note. BEWE = Basic Erosive Wear Examination; IOS = intraoral scanner/scanning; ICC = intraclass correlation coefficient; micro-CT = micro-computed tomography; QLF = quantitative light-induced fluorescence; RMS = root mean square.

3.3 Clinical diagnostic and agreement performance

Alaraudanjoki et al. evaluated BEWE on three-dimensional models in 586 adults and reported high intra- and inter-examiner reproducibility for digital scoring. Nevertheless, digital models tended to yield more severe ETW scores than direct clinical examination, and inter-method agreement for severe wear was only moderate. The findings indicate that digital viewing may increase visibility of morphological defects but is not directly interchangeable with chairside scoring (Alaraudanjoki et al., 2017).

Marro et al. similarly observed that BEWE applied to three-dimensional replicas produced higher scores and detected more initial changes than conventional casts, although the two methods remained strongly correlated (Kendall's $\tau_b = 0.74$) (Marro et al., 2018). These data support digital documentation while also showing that presentation modality affects ordinal classification.

Valdivia Tapia et al. provided more ETW-specific evidence. Agreement between direct and three-dimensional BEWE assessment was substantial overall (weighted kappa approximately 0.70), but concordance was distinctly lower for BEWE 1 than for sound or more advanced lesions (Valdivia Tapia et al., 2025). The primary-tooth validation study showed a similar pattern, with kappa 0.58 and 80% overall agreement for ETW, again illustrating that categorical correspondence is imperfect even when the digital image is high quality (Valdivia-Tapia et al., 2026).

One 2026 clinical diagnostic study provided direct clinical evidence. In 61 adults, on-scan assessment relative to clinical BEWE showed tooth-level sensitivity of 0.98 and specificity of 0.56. Automated assessment

produced different trade-offs, and automated dentine-exposure detection addressed a distinct target. These estimates should be interpreted separately because clinical BEWE is an imperfect, examiner-dependent target-condition assessment rather than an error-free reference standard (O'Toole et al., 2026).

Alharbi et al. compared two digital representations rather than a definitive reference standard. Across 394 occlusal surfaces, three-dimensional IOS and two-dimensional photographs showed 69.5% agreement for BEWE, with weighted kappa 0.57 and Spearman correlation 0.607 (Alharbi et al., 2026). This finding reinforces that different digital documentation modalities should not be assumed to be interchangeable.

3.4 Experimental measurement and validation

Early experimental work established proof of concept for three-dimensional measurement of surface loss. Meireles et al. demonstrated automated wear estimation from digital intra-oral optical scans, providing an early basis for objective sequential analysis (Meireles et al., 2016).

Kumar et al. (2019) evaluated eight natural buccal enamel samples during progressive citric-acid exposure. Maximum profile loss increased from 33.4 to 72.8 μm and correlated with exposure time ($r = 0.877$, $p < 0.001$). Volumetric estimates were less consistent at minimal wear, illustrating that correlation with exposure does not establish interchangeability or a universal detection threshold.

Michou et al. used TRIOS 3 and Patient Monitoring software in a controlled erosive-abrasive model. Significant tissue loss of 0.08 mm was detected after 3 h, and measured loss correlated strongly with acid-immersion time (Spearman $r_s = 0.971$). Based on reported measurement error and uncertainty, surface-profile differences above approximately 0.035 mm were considered true loss within that experimental workflow (Michou et al., 2020). This figure is system-specific and should not be transferred directly to clinical practice.

Witecy et al. (2021) compared TRIOS 3 and Carestream CS3600 measurements with non-contact profilometry. Profilometry measured mean losses of $17.1 \pm 4.7 \mu\text{m}$ after 30-s etching steps and $10.1 \pm 5.1 \mu\text{m}$ after 15-s steps. Both IOS workflows detected stepwise loss, with Bland-Altman analyses showing good agreement with profilometry and no systematic differences, although reported error varied by scanner and software.

Machado et al. (2022) evaluated 15 unpolished bovine crowns scanned with TRIOS 3 at 24-h intervals during 168 h of citric-acid exposure. WearCompare-derived volume and area loss became statistically detectable after 72 and 96 h, respectively, whereas Patient Monitoring-derived depth became detectable after 144 h. Correlations with exposure time were high for depth ($r = 0.9993$), volume ($r = 0.9968$), and area ($r = 0.9475$), but these correlations do not establish agreement with an independent metrological reference.

Jablonski-Momeni et al. extended validation to enamel surfaces adjacent to orthodontic brackets. IOS detected significant progression after repeated erosive cycles and measurements were significantly associated with quantitative light-induced fluorescence (QLF), supporting the ability to identify controlled erosive change in geometrically more complex settings (Jablonski-Momeni et al., 2023).

Loumprinis et al. specifically investigated registration, a central source of uncertainty in longitudinal wear analysis. Several alignment approaches produced broadly comparable measurements, although tooth-level best-fit methods become problematic when extensive tissue loss affects the surfaces assumed to be stable (Loumprinis et al., 2024).

Aly et al. compared Carestream 3700 with three-dimensional confocal laser microscopy. Both methods detected progression after repeated erosion, but IOS did not consistently identify the first-hour change and statistically significant correlation with confocal measurements emerged at later exposure (Aly et al., 2025). This study illustrates a practical lower detection boundary even under controlled conditions.

Tsiafita et al. (2026) compared TRIOS 3, Primescan, and Omnicam with micro-CT after an erosive-abrasive challenge. Mean root-mean-square (RMS) deviation was lowest for micro-CT ($0.0109 \pm 0.0035 \text{ mm}$), followed by TRIOS 3 ($0.0350 \pm 0.0232 \text{ mm}$), Primescan ($0.0590 \pm 0.0302 \text{ mm}$), and Omnicam ($0.1709 \pm 0.0794 \text{ mm}$). Significant between-system differences ($p < 0.001$) indicated that the methods were not interchangeable.

3.5 Longitudinal monitoring and progression

Marro et al. used paired historical orthodontic casts digitised with TRIOS to investigate progression over approximately 2 years. Three-dimensional BEWE scoring detected significant longitudinal change and identified more initial lesions than conventional cast assessment (Marro et al., 2018). In a subsequent quantitative analysis of first-molar surface pairs, median volume loss was greater in visually progressing than non-progressing surfaces. A volume threshold of -1.22 mm^3 yielded 79% sensitivity, 61% specificity and an area under the receiver-operating-characteristic curve (AUC) of 0.80 for visually defined progression (Marro et al., 2020).

O'Toole et al. evaluated direct serial intraoral scans over approximately 3 years. Data from 556 surfaces in 29 patients were analysed using multilevel modelling to account for patient and surface structure (O'Toole et al., 2020a). This study highlights that longitudinal IOS monitoring depends on successful scan acquisition, registration, surface selection, and transparent reporting of exclusions and reliability estimates.

A companion method-comparison study showed that acquisition method, analysis software and measurement metric significantly influenced quantitative estimates. Differences were evident when intraoral scans were compared with precision profilometry and when Geomagic and WearCompare were applied to the same underlying wear data (O'Toole et al., 2020b). This supports treating the digital pipeline as an integrated measurement system.

The prospective study by Marro et al. followed adolescents with baseline and one-year TRIOS scans. Quantitative analysis of 295 surfaces from 70 participants used multilevel regression and demonstrated measurable progression, with baseline clinical and behavioural variables associated with subsequent volume loss (Marro et al., 2022).

Bors et al. provided longer-term observational data. At 10-year follow-up, clinical erosion incidence was 23.2% among 517 re-examined participants. In a digitally analysed subset of 40 participants, mean enamel loss was $137 \pm 79 \text{ }\mu\text{m}$ and digital measurements showed moderate correlation with BEWE ($r = 0.58$) (Bors et al., 2025). Interpretation is limited because baseline records were digitised from casts whereas follow-up used direct Medit i700 scanning, creating a mixed acquisition pathway.

3.6 Methodological quality

Methodological quality varied by design and is summarised in Table 2. Experimental studies commonly used small specimen numbers and incompletely reported sample-size planning, randomisation, allocation concealment, operator blinding, and prespecified analysis. These limitations reduce confidence in estimates of early detection and may exaggerate apparent performance.

Clinical diagnostic and agreement studies were limited by selected samples and by imperfect or modality-dependent target-condition assessment. For O'Toole et al. (2026), the three reported estimates (on-scan BEWE, automated BEWE, and automated dentine-exposure detection) were considered separately because they address distinct targets; applicability to routine clinical assessment is closer for on-scan assessment than for automated outputs. Longitudinal studies were additionally affected by attrition, alignment failure, and incomplete handling of repeated measures.

Unit-of-analysis concerns were important because several studies analysed many teeth or surfaces nested within relatively few participants or specimens. Multilevel modelling reduced this concern in some longitudinal analyses, whereas unadjusted surface-level analyses may have produced overly narrow uncertainty. Certainty was judged low for clinical diagnostic/agreement performance, low for longitudinal clinical monitoring, and very low-to-low for experimental measurement validation (Table 3) because of small samples, heterogeneity, platform dependence, and indirectness to routine clinical care.

Formal publication-bias testing was not feasible. Qualitative assessment could not exclude publication or selective-reporting bias, particularly because small experimental studies with favourable detection results may be more likely to be published and because funding or manufacturer involvement was incompletely reported across the evidence base.

Table 2. Methodological appraisal of the discussed reports

Report	Evidence type	Appraisal	Principal methodological observations
Meireles 2016	In vitro validation	Narrative appraisal	Small sample; limited reporting of some bias-control procedures.
Alaraudanjoki 2017	Clinical agreement	Narrative appraisal	Large clinical sample; clinical BEWE is an imperfect comparator.
Marro 2018	Retrospective longitudinal	Narrative appraisal	Retrospective selection; strong examiner calibration/reliability.
Kumar 2019	In vitro validation	Narrative appraisal	n=8; no formal sample-size calculation; operator error quantified.
Marro 2020	Retrospective monitoring	Narrative appraisal	Power calculation and high repeatability; surface-level analysis requires clustering caution.
Michou 2020	In vitro validation	Narrative appraisal	n=12; controlled workflow; limited blinding/sample-size reporting.
O'Toole 2020 J Dent	Longitudinal cohort	Narrative appraisal	Appropriate multilevel analysis; substantial surface exclusions due to alignment.
O'Toole 2020 JMIR	Method comparison	Narrative appraisal	Scanner/software effects; reporting discrepancy in participant counts between sections.
Witecy 2021	In vitro validation	Narrative appraisal	Good reference-method validation; randomisation/blinding incompletely reported.
Marro 2022	Prospective longitudinal	Narrative appraisal	Prospective design and multilevel modelling; selected quantitative analysis sample.
Jablonski-Momeni 2023	In vitro validation	Narrative appraisal	Larger experimental sample; in vitro translation remains limited.
Loumprinis 2024	In vitro validation	Narrative appraisal	Small experimental model; directly relevant alignment comparison.
Bors 2025	Longitudinal cohort	Narrative appraisal	Digital subset n=40 and mixed baseline/follow-up acquisition pathway.
Valdivia Tapia 2025	In vitro agreement	Narrative appraisal	Strong examiner calibration; same evaluator/direct and digital assessment may influence agreement.
Aly 2025	In vitro validation	Narrative appraisal	Reference microscopy strong; flat controlled specimens limit generalisability.

Report	Evidence type	Appraisal	Principal methodological observations
Tsiafitsa 2026	In vitro validation	Narrative appraisal	n=10; micro-CT comparator; registration-dependent workflow.
Valdivia-Tapia 2026	In vitro validation	Narrative appraisal	Well-defined visual/digital comparison; laboratory primary-tooth setting.
O'Toole 2026	Diagnostic accuracy	Narrative appraisal	Separate judgments required for on-scan BEWE, automated BEWE, and automated dentine-exposure estimates.
Alharbi 2026	Retrospective digital agreement	Narrative appraisal	2D photograph is comparator, not definitive reference; retrospective records.
Machado 2022	In vitro validation	Narrative appraisal	Small bovine experimental sample; no independent metrological reference; correlation with exposure time does not establish trueness.

Note. Appraisal was narrative and design-specific; observations were not converted into a common numerical scale and reflect the judgement of a single reviewer.

Table 3. Certainty of the evidence by domain

Evidence domain	Certainty	Main reasons for downgrading	Interpretive implication
Clinical diagnostic/agreement performance	Low	Few direct clinical studies; imperfect target-condition assessment; platform dependence; incomplete precision reporting	May support adjunctive assessment, but stand-alone diagnostic performance is uncertain.
Longitudinal clinical monitoring	Low	Selected cohorts; attrition/alignment failures; overlapping datasets; heterogeneous workflows	Serial documentation appears feasible, but magnitude and minimum detectable change are uncertain.
Experimental measurement validation	Very low to low	Small samples; indirectness; inconsistent blinding/randomisation; heterogeneous comparators and outcomes	Demonstrates analytical capability under controlled conditions but cannot establish routine clinical effectiveness.

4. Discussion

4.1 Principal findings

Available evidence, derived predominantly from small and heterogeneous experimental studies, suggests that IOS-based workflows may provide useful adjunctive information for ETW documentation and longitudinal monitoring. Direct clinical diagnostic evidence remains limited. The more consistent signal concerns serial quantitative documentation, provided that acquisition and registration are reproducible and stable reference surfaces remain available.

A central distinction is analytical sensitivity versus clinical diagnostic performance. Laboratory studies detected changes in the tens-of-micrometres range and showed associations with controlled exposure, yet the same magnitude of performance cannot be assumed in patients. Experimental specimens can be immobilised, reference areas can be protected, and exposure can be standardised. Clinical scans must cope with limited access, moisture, restorations, variable scan paths and progression within the surfaces used for alignment.

The earliest category of ETW remains particularly difficult. Valdivia Tapia et al. (2025) reported poorer agreement for original BEWE score 1 than for sound or more advanced surfaces, and primary-tooth validation showed a similar pattern. BEWE 2.0 clarifies the distinction between scores 0 and 1 and adds a new level 4 score for severe loss (≥ 2 mm loss of crown height or 2 mm horizontal cervical wear) (Bartlett et al., 2026); future validation studies should state explicitly which version is used and should not assume direct comparability with studies based on the original index.

The 2026 O'Toole study provides an important bridge between visual digital assessment and conventional clinical examination (O'Toole et al., 2026). High sensitivity with lower specificity suggests that scans may identify more candidate lesions than chairside scoring. Because BEWE itself is not a perfect gold standard, disagreement cannot be assigned entirely to either modality. Digital magnification and viewing angle may reveal true morphology missed clinically, but digital presentation may also encourage overcalling. Independent validation against robust reference conditions is therefore essential before describing such differences as false positives or false negatives in an absolute sense.

A second major finding is that performance belongs to the complete digital workflow. The method-comparison study by O'Toole et al. showed that scanner precision, analysis software and measurement metric changed quantitative outputs (O'Toole et al., 2020b). Tsiafitsa et al. further demonstrated substantial between-scanner differences relative to micro-CT (Tsiafitsa et al., 2026). Consequently, a threshold derived from one scanner-software-registration combination should not be assumed valid for another.

4.2 Clinical implications

The most defensible present clinical role of IOS is as an adjunct for serial documentation and monitoring. Conventional examination remains necessary to integrate symptoms, history, aetiology, activity and restorative status. IOS adds a quantitative layer that may be especially useful when the question is whether previously documented wear has progressed.

Consistency across visits is likely more important than maximising a single nominal scanner specification. Wherever possible, follow-up should use the same scanner family, scanning strategy, software and analysis protocol. Stable reference surfaces should be selected cautiously, and changes in restorations, fractures or extensive wear within proposed reference areas should trigger re-evaluation of registration quality.

The evidence does not support a universal minimum clinically detectable change. The approximately 0.035-mm threshold discussed by Michou et al. arose from the error structure of a specific experimental TRIOS workflow (Michou et al., 2020). Likewise, the -1.22-mm³ threshold reported by Marro et al. was derived from a specific first-molar analysis and achieved moderate specificity (Marro et al., 2020). These values are informative validation results, not general chairside cut-offs.

Serial surface maps may have potential value for patient communication and engagement because they can illustrate progression more intuitively than changes in an ordinal score. However, this patient-centred outcome was not directly evaluated in the included studies and should be tested rather than assumed.

4.3 Methodological considerations and heterogeneity

The evidence synthesised here addressed several different constructs: ordinal agreement, examiner reliability, quantitative trueness, precision, repeatability, correlation and diagnostic sensitivity/specificity. These metrics should not be collapsed into a single concept of 'accuracy'. A high correlation can coexist with systematic bias, while strong repeatability does not establish trueness.

Registration is a recurrent methodological bottleneck. Sequential models must be placed into a common coordinate system using regions assumed to be stable. Generalised ETW challenges this assumption because apparently intact reference surfaces may also undergo small changes; therefore, exclusion criteria, registration quality, and analysable surface counts should be reported transparently (O'Toole et al., 2020a). Loumprinis et al. showed that several alignment strategies can perform similarly in controlled models but that the amount and distribution of wear determine the reliability of the reference geometry (Loumprinis et al., 2024).

The unit of analysis is another important issue. Surface-level sample sizes can appear large despite being nested within a modest number of participants or specimens. Multilevel models used in some longitudinal studies provide a stronger analytical approach because they explicitly account for patient-level and surface-level dependency (O'Toole et al., 2020a; Marro et al., 2022). Future studies should consistently identify the hierarchy of measurements and report how clustering was handled.

Clinical reference standards also remain problematic. BEWE is clinically useful, but it was designed as a practical ordinal index rather than a micrometre-scale reference system. Studies comparing IOS directly with clinical BEWE therefore evaluate agreement with a clinical construct, not absolute physical truth. Experimental reference methods such as profilometry, confocal microscopy or micro-CT offer more precise physical comparators but at the cost of reduced clinical realism.

4.4 Strengths and limitations of this review

A principal strength of this review is the focused distinction between ETW-specific evidence and broader non-carious tooth-wear literature. Laboratory validation, clinical agreement and longitudinal monitoring were considered separately so that analytical sensitivity was not presented as synonymous with in vivo diagnostic validity. The review also explicitly considered unit-of-analysis and clustering issues that are particularly important in dental surface research.

Several limitations must be acknowledged. First, as a narrative review, this synthesis did not apply formal systematic-review procedures such as protocol registration, duplicate independent screening and appraisal, or itemised risk-of-bias instruments, so study selection and appraisal reflect the judgement of a single reviewer. Second, citation searching and grey-literature searching were limited, and at least one relevant report (Machado et al., 2022) was identified only through post-search citation checking. Third, the evidence was heterogeneous and included small experimental samples, selected clinical cohorts, and related publications from overlapping datasets. Fourth, funding and manufacturer involvement were incompletely reported in several source studies, and selective reporting could not be excluded.

These limitations precluded meta-analysis and reduce certainty in any general estimate of IOS performance. Qualitative sensitivity considerations did not change the direction of the main interpretation: the evidence remained more supportive of adjunctive longitudinal documentation than of stand-alone clinical diagnosis, and conclusions weakened when cast-based, mixed-pathway, or methodologically unclear studies were excluded.

Several included workflows were platform-specific, and at least one recent clinical study reported manufacturer funding and author affiliations with the manufacturer. Such involvement does not establish bias, but it reinforces the need for transparent reporting and independent external validation.

4.5 Future research

Future research should prioritise prospective multicentre clinical cohorts using prespecified scanning and registration protocols. Scanner model, software version, scan strategy, registration algorithm, reference surfaces and analysis metric should all be reported in sufficient detail for replication.

Studies should define clinically meaningful progression independently from scanner measurement error and should distinguish repeatability from trueness. Where multiple teeth or surfaces are analysed per participant, hierarchical statistical models should be planned a priori. Robust comparison with physical reference methods is still needed for analytical validation, while clinical validation should include independent examiner assessment and clinically relevant activity/progression outcomes.

Automated or algorithm-assisted assessment may improve repeatability and scalability, but automated outputs require independent external validation before routine clinical use. The key goal is not simply greater numerical sensitivity; it is a validated digital workflow that can identify clinically meaningful change with known uncertainty.

5. Conclusions

Available evidence suggests that intraoral scanner-based workflows may be useful adjuncts for documenting and longitudinally monitoring erosive tooth wear. However, the evidence base is dominated by small, heterogeneous experimental studies, while direct clinical diagnostic evidence remains limited.

Measurement performance depends on the complete acquisition, registration, and analysis workflow. Thresholds derived from individual scanner-software combinations should not be generalised across platforms, and correlation alone should not be interpreted as measurement agreement or clinical interchangeability.

IOS should therefore complement rather than replace conventional clinical assessment until standardised prospective clinical validation is available. Future studies should use prespecified outcomes, independent reference methods, appropriate hierarchical analyses, transparent funding disclosures, and external validation of automated algorithms.

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Data availability: Database search strategies are reproduced in Supplementary Table S1. No new datasets were generated or analysed during this review.

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SUPPLEMENTARY MATERIAL

Supplementary Table S1. Full search strategies

PubMed/MEDLINE (352 records)

("Tooth Erosion"[Mesh] OR "Tooth Wear"[Mesh] OR "erosive tooth wear"[tiab] OR "dental erosion"[tiab] OR "tooth erosion"[tiab] OR "erosive wear"[tiab] OR "tooth wear"[tiab] OR "dental wear"[tiab] OR ((tooth[tiab] OR teeth[tiab] OR dental[tiab] OR enamel[tiab] OR dentin*[tiab]) AND eros*[tiab]))

AND

("intraoral scan*[tiab] OR "intra-oral scan*[tiab] OR "intraoral scanner*[tiab] OR "intra-oral scanner*[tiab] OR "digital intraoral scan*[tiab] OR "digital impression*[tiab] OR "digital dental model*[tiab] OR "digital model*[tiab] OR ((3D[tiab] OR "three dimensional"[tiab] OR "three-dimensional"[tiab]) AND (scan*[tiab] OR model*[tiab] OR imag*[tiab])) OR TRIOS[tiab] OR "True Definition"[tiab] OR CS3600[tiab] OR CS3700[tiab] OR Primescan[tiab] OR Omnicam[tiab] OR iTero[tiab])

Embase (146 records)

('tooth erosion'/exp OR 'tooth wear'/exp OR 'erosive tooth wear':ti,ab,kw OR 'dental erosion':ti,ab,kw OR 'tooth erosion':ti,ab,kw OR 'erosive wear':ti,ab,kw OR 'tooth wear':ti,ab,kw OR 'dental wear':ti,ab,kw OR ((tooth OR teeth OR dental OR enamel OR dentin*) NEAR/3 eros*):ti,ab,kw)

AND

('intraoral scan*':ti,ab,kw OR 'intra-oral scan*':ti,ab,kw OR 'intraoral scanner*':ti,ab,kw OR 'intra-oral scanner*':ti,ab,kw OR 'digital intraoral scan*':ti,ab,kw OR 'digital impression*':ti,ab,kw OR 'digital dental model*':ti,ab,kw OR 'digital model*':ti,ab,kw OR '3d model*':ti,ab,kw OR '3d image*':ti,ab,kw OR '3d scan*':ti,ab,kw OR 'three-dimensional model*':ti,ab,kw OR 'three-dimensional image*':ti,ab,kw OR 'three-dimensional scan*':ti,ab,kw OR 'three-dimensional model*':ti,ab,kw OR 'three-dimensional image*':ti,ab,kw OR 'three-dimensional scan*':ti,ab,kw OR trios:ti,ab,kw OR 'true definition':ti,ab,kw OR cs3600:ti,ab,kw OR cs3700:ti,ab,kw OR primescan:ti,ab,kw OR omnicam:ti,ab,kw OR itero:ti,ab,kw)

Scopus (211 records)

TITLE-ABS-KEY(("erosive tooth wear" OR "dental erosion" OR "tooth erosion" OR "erosive wear" OR "tooth wear" OR "dental wear" OR ((tooth OR teeth OR dental OR enamel OR dentin*) W/3 eros*)) AND ("intraoral scan*" OR "intra-oral scan*" OR "intraoral scanner*" OR "intra-oral scanner*" OR "digital intraoral scan*" OR "digital impression*" OR "digital dental model*" OR "digital model*" OR "3D model*" OR "3D image*" OR "3D scan*" OR "three-dimensional model*" OR "three-dimensional image*" OR "three-dimensional scan*" OR "three-dimensional model*" OR "three-dimensional image*" OR "three-dimensional scan*" OR TRIOS OR "True Definition" OR CS3600 OR CS3700 OR Primescan OR Omnicam OR iTero))